Risk Assessment of Lithium-Ion Battery Manufacturing and Recycling using Fuzzy FMECA

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INTRODUCTION

- Growing use of lithium-ion batteries (LIBs) has intensified safety concerns during manufacturing and recycling.
- Processes involve flammable, reactive, and toxic materials, leading to fire and explosion risks.
- Conventional FMECA struggles with uncertainty and subjective expert evaluations.
- This study applies Fuzzy FMECA to identify and prioritize critical hazards, improving process safety and decision-making.

METHODOLOGY

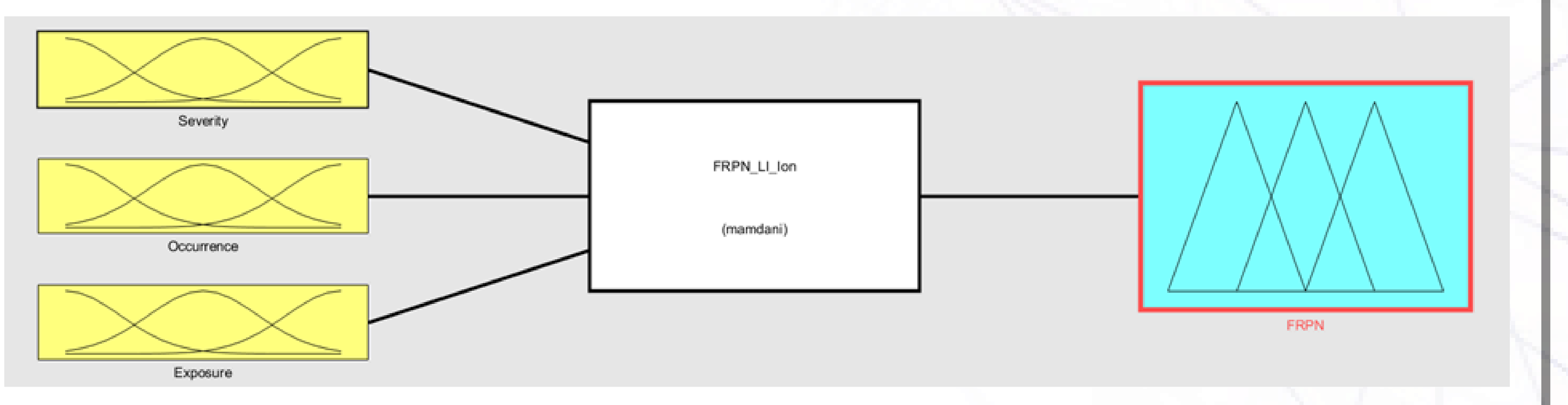
- **Process Mapping:**
- Key stages identified — collection, dismantling, shredding, separation, and recovery in LIB manufacturing and recycling.
- **Failure Mode Identification:**
- Major hazards include thermal runaway, flammable vapor emission, combustible dust generation, and chemical exposure.
- **Fuzzy Parameter Definition:**
- Three inputs — Severity (S), Occurrence (O), and Exposure (E) — each defined with five linguistic levels (Very Low to Very High).
- **Rule Base Development:**
- A Mamdani-type FIS created with 125 fuzzy rules linking inputs to the Fuzzy Risk Priority Number (FRPN) output.
- **Defuzzification:**
- The Center of Gravity method used to obtain precise FRPN values for risk ranking and prioritization.

CONCLUSION

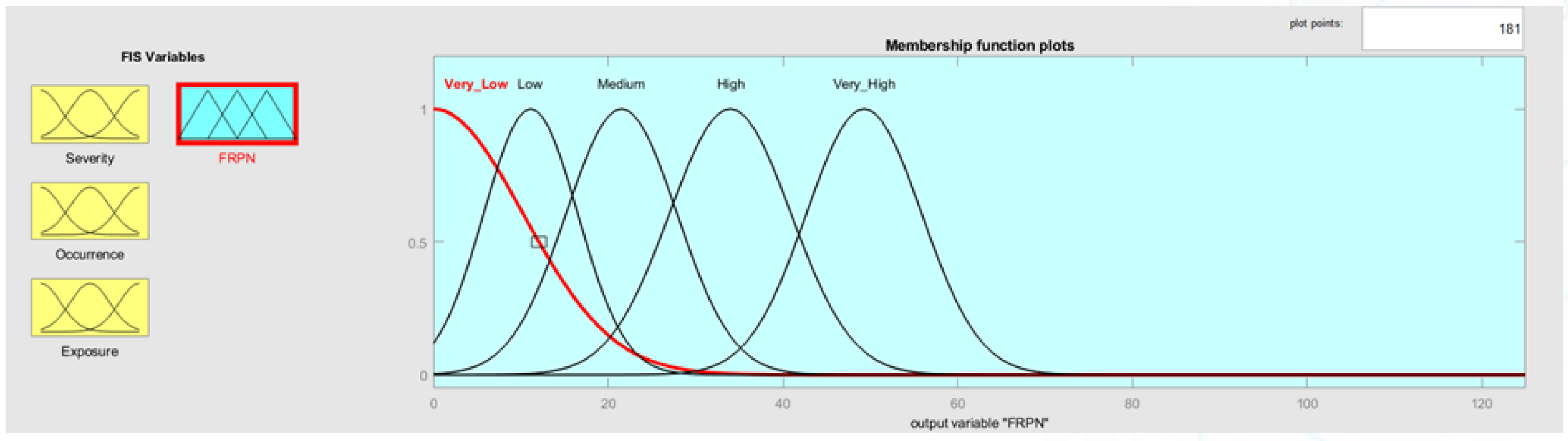
- The Fuzzy FMECA framework effectively evaluates process safety risks in lithium-ion battery manufacturing and recycling.
- It integrates expert judgment under uncertainty, providing a more reliable and quantitative risk prioritization.
- Thermal runaway, vapor emission, and dust generation emerged as the most critical hazards.
- The approach supports proactive safety management and can be extended to real-time risk monitoring in future work.

RESULTS

- The developed Fuzzy Inference System (FIS) combines Severity, Occurrence, and Exposure to generate a Fuzzy Risk Priority Number (FRPN) (Fig. 1).
- Membership functions ensure smooth transitions between linguistic inputs, effectively handling uncertainty in expert judgments (Fig. 2).
- The rule evaluation output confirms logical variation of FRPN with input changes, validating the accuracy and reliability of the fuzzy model (Fig. 3).
- Thermal runaway, vapor emission, and combustible dust generation were identified as high-risk failure modes.
- The fuzzy approach provided more consistent and objective risk ranking than traditional FMECA.



- Figure 1: Fuzzy Inference System (FIS) structure integrating Severity, Occurrence, and Exposure as inputs to generate the Fuzzy Risk Priority Number (FRPN).



- Figure 2: Membership functions for input and output variables showing smooth transitions across linguistic levels.

- Figure 3: Rule evaluation output illustrating defuzzified FRPN values and the system's logical response to varying input conditions.